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DESIGN AND ANALYSIS OF COMPOSITE ROCKET MOTOR CASING

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ABSTRACT

Rocket motors are extensively used to produce thrust or impulsive force to impart a preferred velocity to flight vehicle to convey its shipment to the proposed target. The working principle of the Rocket motor is mostly Newton's 2nd and 3rd laws. Rocket motors are non-air inhalation propulsion class i.e., won't involve oxygen from the atmosphere for combustion of the fuel which is stored in the rocket motor. Through the operating situation of the motor hardware, it will be subjected to high temperatures and pressure loads. Structural and thermal design has to be carried out for a given input parameters and analysis to be carried out to check the stress levels and temperatures on the rocket motor. This research work has been accepted out with structural design of motor hardware. The main input parameters measured are the maximum working pressure and maximum diameter of the motor hardware.

For design, the motor hardware is measured as a pressure vessel. To calculate parameters like thickness some initial assumptions were finished. 2D drawing has urbanized using solid works software and for structural and thermal analysis is approved out in ANSYS. This software employs finite element analysis techniques to generate the solution. Hence the displacement magnitude, von Mises stress and strain developed within the motor. From this analysis the suitable material can be proposed, suggested for the future work.

KEYWORDS: Composite, Rocket & Motor Casing

Original Article

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1. INTRODUCTION

The propellant comprises of one or more components mounted straight in the situation of the engine in a solid rocket engine (SRM) that functions as both a propellant tank and a combustion chamber. The propellant is usually intended to protect the case against engine heating. Most modern propellant charges are produced by pouring viscous mix into the engine case with suitable mould fixtures. All rockets worn several kind of powerful or pulverized propellant awaiting the 20th century, while fluid rockets and amalgam rockets accessible extra proficient and convenient alternative. Solid rockets are still worn today in sculpt rockets and in superior applications meant for their effortlessness with consistency.

Because solid rockets container be reliably stored and launched for elongated periods of time on tiny observe, they contain often be worn during martial applications such while armaments. Compared to fluid propellants, the decreased effectiveness of strong propellants does not promote their utilize since the chief thrust in current average-to-great start on vehicles worn to perform superior payloads keen on the path. Though, solids are frequently worn as supplementary fastening-on boosters to augment freight capability or because turn-stabilize put in-on higher stage while senior than normal speeds are requisite.

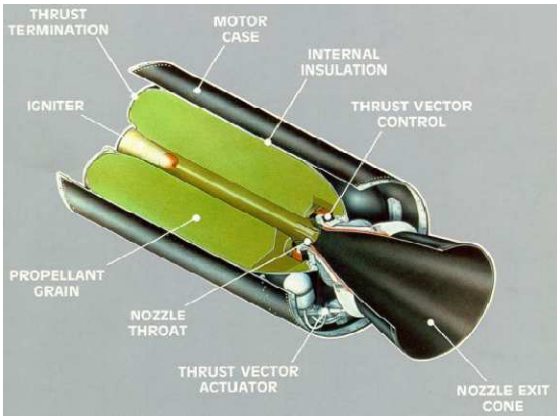


Figure 1: Solid Rocket Propellant Motor.

The typical rocket motor case is basically a right circular double-dome cylinder called skirts with opening in both domes and cylindrical extensions. The opening at the back interfaces with the nozzles. The opening forward is suitable for the igniter and secure arm. The engine case for a strong propulsion rocket engine serves to safeguard and store the propellant grain until the engine is used as a high-pressure combustion chamber, high-temperature grain burning during engine activities, mechanically/structural interface with other engine parts such as the nozzle, igniter, inner insulation, handling/carrying brackets, etc. Since the case of the engine is an inert or non-energy missile element, the goal of the design is to create the case as light as possible. This will lead in a greater proportion of the engine mass and high efficiency of the engine and missile. The significant factors that require appropriate caution during material and the choice is as follows: material strength, elevated material temperature properties, rigidity or deformation features, resistance to corrosion and ease of manufacture. A significant factor in the design of the rocket motor instances is the choice of materials with a high specific strength. Maraging steel is one of the greatest specific strength single case products used in rocket motor cases manufacturing. Attempts to use greater particular strength steels have developed severe quality control issues due to their decreased ductility and is some cases of fragile behavior. Composites, on the other side, can be built to exceed any steel's efficient particular power.

Combining two or more separate materials, each of which maintains its unique characteristics to produce a fresh material, makes a composite material frequently. One is a strong material in these two products and the other is a binding material that holds both components together. The resulting composite material or composite is combined in such a way that it possesses superior properties that cannot be obtained with a single constituent material. In technical terms, therefore, a composite is a multi-phase material from a mixture of components, differentiated in structure or shape, which stay bonded together but maintain their identities and characteristics without going into any chemical reactions. The parts are not dissolving or merging entirely. They maintain an interface between themselves and act in concert to achieve improved, specific or synergistic characteristics that cannot be obtained by any of the initial parts acting alone.

1.1 Main Parts of Solid Propellant Rocket Motors

An effortless solid rocket motor consists of a case, plunger, grain (catalyst load) and igniter. The grain functions as a powerful mass predictably burning and produce drain gases. The plungers sizes are considered to preserve a chamber intend heaviness though the drain gasses generate thrust.

Once ignite, a straightforward solid rocket engine cannot be fasten down since it contain all the parts required for ignition inside the cavity where they are burn. Not only is it feasible to throttle more advanced solid rocket motors, but it is

also feasible to extinguish them and then re-ignite them by calculating the plunger geometry or using vent ports. Also available are pulsed rocket engines that burn in segments and can be fired on command.

1.1.1 Motor Casing

In the event of the engine, the combustion takes place; therefore, it is sometimes referred to as the chamber of combustion. With an adequate safety factor, the situation must be able to withstand the internal pressure arising from the operation of the engine, roughly 3–30 MPa. Motor case is therefore generally produced from either metal (high-struggle steels or aluminum alloys of lofty potency) or complex equipment (glass, kevlar and carbon).

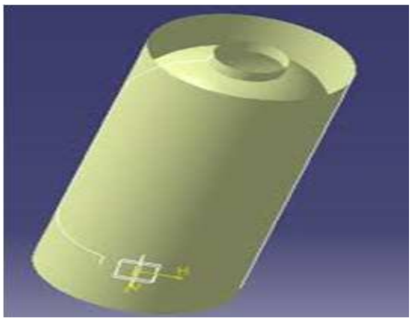


Figure 1.1: Motor Casing.

1.1.2 Insulation

High combustion gas temperature ranging from approximately 2000 to 3500 K requires rocket motor case protection or other structural subcomponents. Emblematic insulator equipment has low thermal conductivity, lofty warm capability, and it is regularly feasible to cool ablatively. The nearly all frequently worn padding equipments are EPDM (Ethylene Propylene Diane Monomer) through the totaling of reinforcing parts.

1.1.3 Igniter

The detonation scheme offers the power required for the catalyst exterior to be combusted. The detonation typically starts through an electrical gesture. The allege of ignition has a high detailed liveliness and is deliberate to liberate either gasses or powerful particle. Standard heat release compounds are typically pyrotechnic materials, black powder, metal oxidant formulations and normal solid rocket catalyst.

1.2 Working Principle

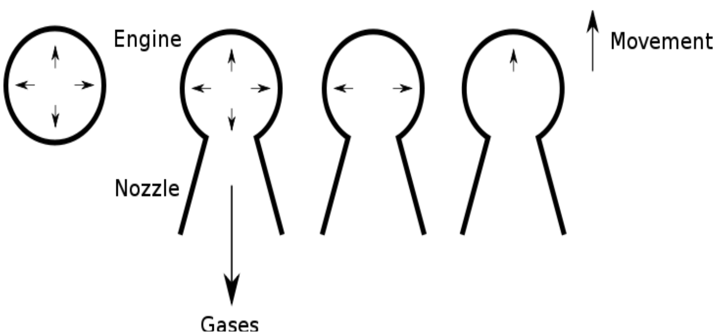


Figure 1.2: Working Principle.

By expelling a high-speed fluid exhaust, rocket engines generate thrust. This fluid is roughly for eternity a gas shaped by burning of solid or fluid propellants, composed of parts of oil and oxidizer, in a burning cavity by elevated pressure (10–200 bar).

The exhaust fluid is then transported by a supersonic propelling plunger using the warmth power of the gas to go faster the tire to extremely elevated velocity, and the response to this push the train within the reverse track.

For outstanding outcomes, elevated temperature and pressure in the rocket engines are extremely enviable while this enables the engine to be fitted with a long nozzle, which offers superior tire speed because glowing as improved thermodynamic competence.

1.3 Scope

- Design of a rocket motor casing (including the COSMOS's analysis).
- Fabricate the rocket motors.
- Analysis and report writing.

2. LITERATURE REVIEW

- The equations for shell and dome thickness calculation are provided in Section VIII section 2 of the ASME Pressure vessel code. Alexander flake developed an equation for calculating the minimum bolt area and flange thickness required. This technique is called as the technique of Schneider.
- NASA SP-8025 has given data on the distinct solid rocket engines ' material features. Based on these material features, the material is selected for the solid rocket motor to withstand the pressures that will influence the casing of the engine.
- NASA provided the information of the solid rocket engine with preliminary design review and structural analysis of the solid rocket engine joint including metal and non-metallic components. At certain operating temperatures, a structural analysis is performed to verify the structural integrity of the solid rocket engine.
- NASA supplied a robust propellant performance prediction and analysis. Based on this, the solid propellant rocket engine's efficiency is structured by considering the loads that will affect the solid rocket engine's casing. The efficacy of this method is anticipated and evaluated by evaluating the response thrust generated by the pressure-imparted momentum of the extended exhaust gasses. Mathematical modeling used to simulate the internal flow areas of solid rocket combustion chamber is quite useful for predicting stable and transient flow.

3. SOLID ROCKET MOTOR

Solid rocket motors serve as the backbone propulsion for strategic and tactical missiles as well as for satellite launch vehicles. They give the car the speed needed when the stage is burned off. After thorough system studies considering maximum allowable vehicle acceleration and burning out altitude from the dynamic pressure view, the rocket motor specification will be selected for the thrust versus time. Since, most missions do not require the sophistication of different restart and throttling activities, strong propulsion becomes an overwhelming option because of its inherent safety, high reliability, ease of handling, simplicity, minimal maintenance, effectiveness of packaging, efficient system integration and low price.

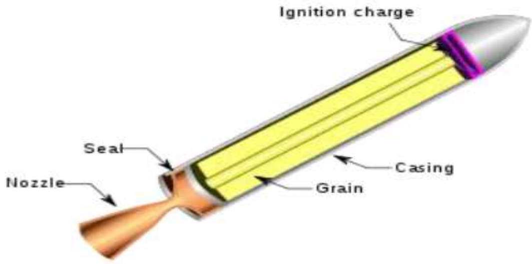


Figure 3.1: Solid Propellant Rocket Motor.

Because of the following reasons, strong rocket engines inherently have high reliability and reduced expenses: Minimum amount of parts.

- No moving components necessary to provide propulsive force.
- No complicated operating or diagnostic electronic control systems.
- No need for pressurized liquids that may leak or require dangerous gasses to be released.
- No missile engine maintenance.

3.1 Problem Statement

This project is about developing the optimum rocket engine for a tiny launcher and conducting a rocket engine study. In this project, the rocket motor worked as a device that produced thrust in the launch of the rocket. In the rocket sector, the rocket engine is generally constructed using the nozzle theory and small fluid where the design and structure of the rocket is the main point in developing a nice rocket engine. To assist the rocket during launch, the right design and size of the rocket engine must be developed and any failure will bring risk to the individuals in the rocket if the rocket explodes.

Normally solid rocket engines are intended to resist the stress contained by the enclosure and supply solidity to the structure. The main design contemplation is with the intention of there will be uniform pressure throughout the casing due to the effect of propellant burning in the case. Solid rocket engines are generally designed to withstand 100°C temperature. But the temperatures induced in the case are ranging from 1000°C to 3000°C in actual life. Some ablative liners are given inside the case to resist these elevated temperatures. In the structural analysis, the results are compared to the thermo-structural analysis.

4. ROCKET PROPELLENT

Rocket catalyst is a fabric that is moreover used straight through a rocket as a response gathering (dynamic crowd) to facilitate is expelled from a rocket engine, typically at very high speeds, to make the force with hence give the spaceship momentum, or ultimately toward fabricating the response throng within a substance response. Every category of rocket require a distinct type of catalyst: exothermic substance responses want chemical generators that afford the power to move the ensuing gasses during the plunger. Thermal missiles utilize tiny static molecular mass propellants are chemically well-suited through the heat scheme at elevated temperatures, though chilly gas thrusters utilize hassled and simply store static gas. Electrical momentum needs catalysts to be eagerly ionized or malformed to plasma, plus into the severe situation of nuclear pulsation momentum the catalyst consists of a lot of tiny, non-stick nuclear explosive from which the ensuing upset gesture propel the spaceship absent beginning the volatile, thus generating momentum. Single such spaceship to be called (except not at all build) "scheme Orion" (not to be perplexed through NASA Orion spaceship).

4.1 Chemical Propellants

There are four primary kinds of propellants for chemical rockets: strong, storable fluid, cryogenic liquid, and fluid monopropellant. Bi-propellant mixture solid/fluid rocket motors are also beginning to see restricted use.

5. ROCKET MOTOR PROPULSION

5.1 Principles of Propulsion

In the casing a reaction force (thrust) is created by the ejection of gas.

$$F \approx q.\ Ve$$

After the ejection of gas a chemical reaction takes place, that transforms a liquid or a solid into a gas at high temperature to generate combustion.

5.2 Liquid Propulsion

- High specific impulse.
- Re-ignition and throttling possible.

5.3 Solid Propulsion

We have to work at pressures of several tens to hundred bars to achieve adequate thrusts and eject the gasses at supersonic speeds. Hence, a strong rocket motor's primary components are:

Solid (fuel and oxidizer mixed in one solid block (grain)

- Can deliver high thrust from a limited volume
- Almost immediate availability
- High reliability
- Moderate costs

6. MATERIALS

Generally, several types of materials are used for the production of rocket motor casing. These are different types of materials used for rockets and missile.

6.1 Structural Metallic Materials

- CDV6: low carbon steel used in the engine case of solid rockets.
- M250: High resistance steel marking and high toughness used in solid rocket engine booster case.
- Titanium alloy: (Ti-6Al-4V) used in gas bottles with elevated pressure.
- Aluminum alloys: used in liquid propellant tanks, engine parts, reusable start-up vehicle aircraft. Characteristics: AA 2219, AA2014, AA6061.
- V) Magnesium / Mg -Lithium alloys: used in the upper stage system, such as the payload adopter, the aircraft decks, the bay structure of the equipment.
- VI) Powder metallurgy products: for bi-propellant control thrusters used in the neck of the nozzle.

6.2 Composite Materials

- Carbon F/Kevlar F–Epoxy Resin: used in the case of a strong engine, a pressure vessel, inter stages, an adapter for payload.
- Carbon C/Silica C–Phenolic Resin: used in ablative liners, inserts in the neck of the nozzle.

6.3 Thermo-Structural Materials

- Carbon Fiber/Silicon Carbide Ceramic Matrix: used in heat-shield nose-caps, leading edge and RLV control surface.
- SiC F/SiC Ceramic Composite Matrix: used in high/hot constructions.

7. METHODOLOGY

The rocket motor casing model geometry is complicated and consists of different parts such as composite casing shell, igniter end, nozzle end, skirt end of igniter and skirt end of nozzle. So, as shown in fig, 2D model is developed using solid works. The 2D model is transformed to a strong 3D surface and rotated around 360° around the X-axis to transform it into a strong 3D model surface.

The assessment of metallic casing finite elements is carried out using the workbench of ANSYS16.0.

The 3D strong metallic casing model is imported into IGES format in ANSYS16.0. Meshing is another significant step in the assessment of finite elements. The findings of the evaluation depend on the type component used. To mesh the entire geometry, tetra components (3D meshing) are used. The fixed support is applied to the skirt end of the igniter, pressure 36.888MPa is applied internally and force 4.8001e+006Mpa is applied to the skirt end of the nozzle as shown in Figure. For this purpose metallic casing is meshed with four distinct element sizes (50, 45, 40 and 35) for grid independence study. Convergence is verified with distinct element sizes. Convergence with element size 35 is finally achieved. The node numbers are 71861 and 10116 components are used to generate the mesh for the whole model with element size 40. Figure shows stress outcomes of misses. The peak stress of 6.2005e5 MPa was noted at the igniter skirt end in the case and the minimum stress was noted. The maximum complete deformation of 4683 mm is noted in the case and at the igniter skirt end there is a minimum total deformation.

7.1 Design of Casing

Assumptions in the classical laminate hypothesis (CLT) are also produced in the composite rocket engine casing design. The main regions of assumptions per CLT are:

- The types of fiber and matrix are the same.
- Structure obeys the statute of hooks.
- The fibers are constant and straight.
- Tensile & deformations of compression are the same.
- The shear stresses in the interfaces of the fiber matrix are small.

The design safety factor considered for the current assessment on the ultimate tensile strength is 1.25 and the yield strength is 1.125. Combining helical, hoop layers and dollies, the total thickness of the composite shell casing is obtained.

The shell thickness is acquired depending on the security and working pressure design factor. Each layer's thickness is taken as 0.5 mm and the number of layers is taken as 72 to meet the 36 mm casing shell's necessary thickness. 4518/4518/9018/018] S is the laminate code. The orientation of the ply is symmetrical for the entire shell casing laminate.

For the maximum expected operating pressure (MEOP), the composite rocket motor casing is designed. The selection of composites as the main material in the case design is dictated by the reality that the efficiency factor (as provided by N= PV / W) for composite rocket motor casing is constantly greater than that of metal rocket motor casing. A composite casing's greater efficiency factor is the consequence of certain intrinsic characteristics of composite materials of which greater and tailorable particular strength / stiffness characteristics are critical. In addition to reduce the tooling costs from the manufacturing point of perspective, shorter lead time to understand and tooling convenience to vote for composites to design modifications.

8. MODELLING OF ROCKET CASING

Dimensions of Rocket casing

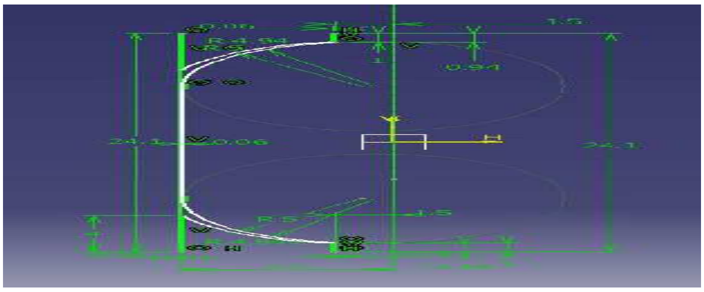


Figure 8.1: Front view of Rocket Casing Dimensions.

Go to Sketch and draw the above figure as per dimensions

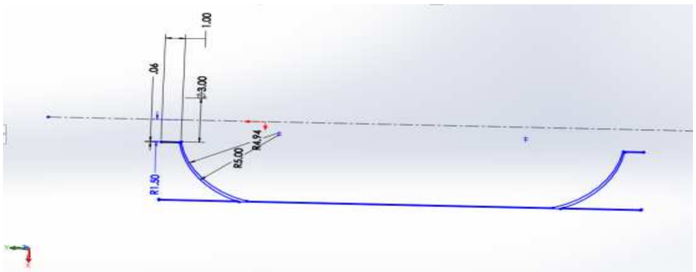


Figure 8.2: Side view of Rocket Casing Dimensions.

Go to features and give the revolve option

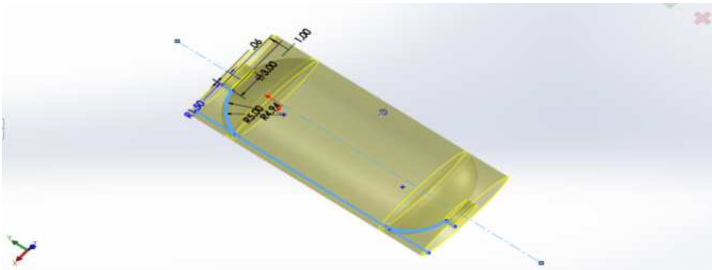


Figure 8.3: Revolve Rocket Motor Casing.

Apply Section view on the above figure

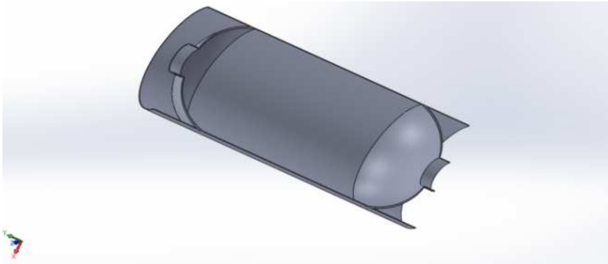


Figure 8.4: Section view of the Rocket Motor Casing.

9. ANSYS ANALYSIS ON ROCKET CASING

The rocket casing solid works model is transformed to IGES to export in the ANSYS software.

After importing the geometry four dissimilar materials are assigned one by one,

They are,

Carbon fiber

Kevlar 29

Kevlar 49

9.1 Material Properties

Table 1

Material	Density (kg/m³)	Young's modulus(Gpa)	Thermal Conductivity	Poisson's ratio
Carbon fiber	2100	100	14.3	0.3
Kevlar 29	1440	74	0.3	0.36
Kevlar 49	1467	100	0.28	0.3

9.2 Static Structural Analysis

A static structural analysis determine the displacements, stresses, strains and forces induced in buildings or parts by loads that do not cause important apathy and damping impacts. Stable loading and reaction situation are presumed; that is, the structure's loads and reaction are presumed to differ slowly over time. A static structural load can be performed using the ANSYS solver.

9.3 Model

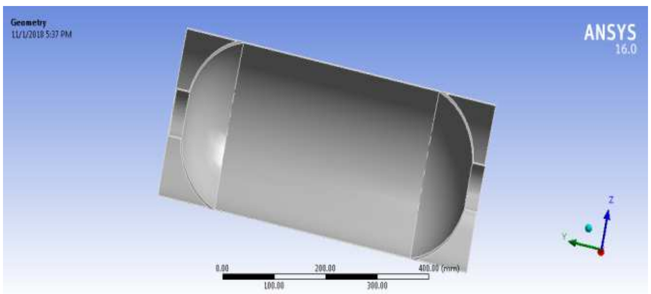


Figure 9.1: Model of the Rocket Motor Casing.

9.4 Mesh

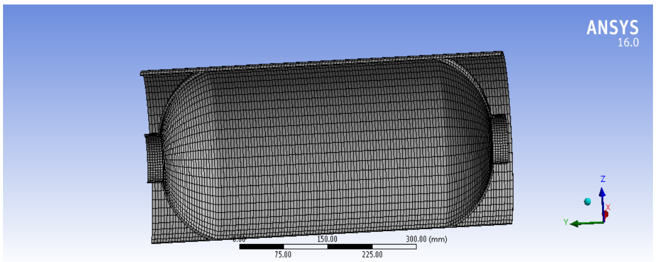


Figure 9.2: Mesh of the Rocket Motor Casing.

Nodes	71861
Elements	10160
Mesh Metric	None

9.5 Boundary Conditions

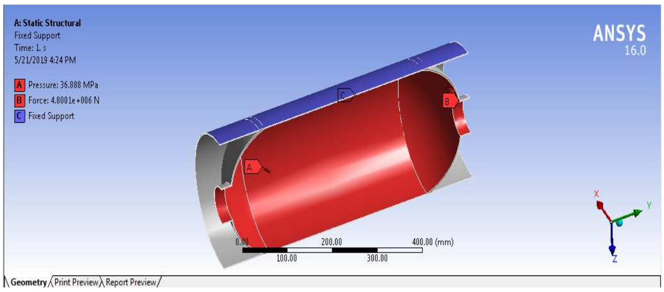


Figure 9.3: Boundary Conditions Applied on the Rocket Motor Casing.

9.6 Pressure: 36.888mpa

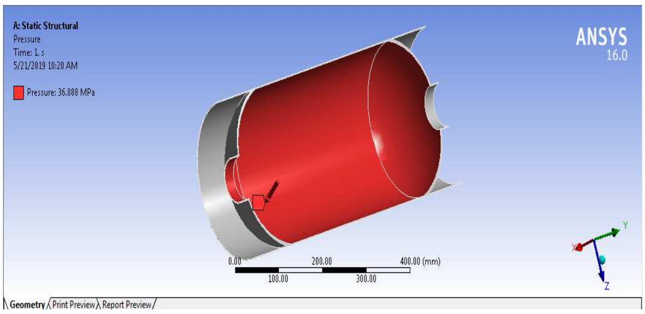


Figure 9.4: Pressure of 36.888 was Applied on the Motor Casing.

9.7 Force: 4.8001e+006N

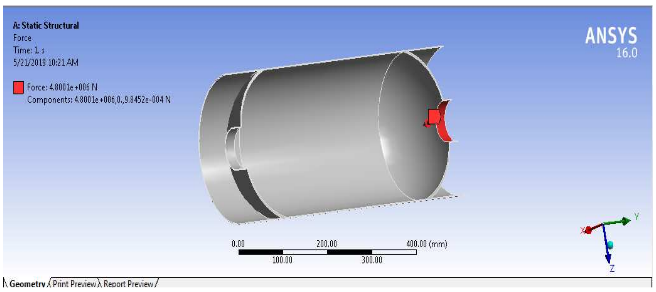


Figure 9.5: Force of 4.8001e+006N was Applied on the Motor Casing.

9.8 Fixed Support

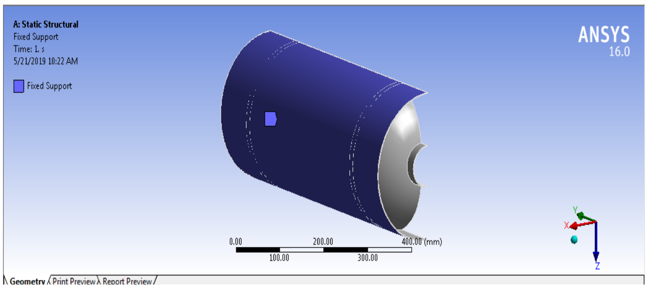


Figure 9.6: Fixed Support was Applied on the Motor Casing.

9.9 Material: Carbon Fiber

9.9.1 Stress

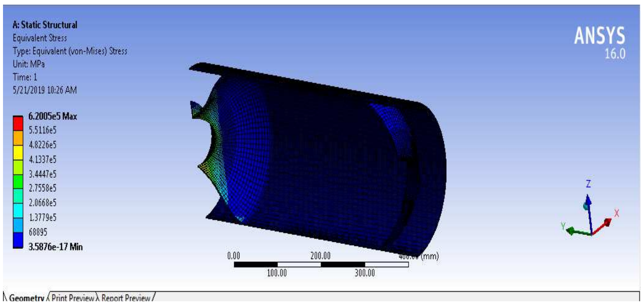


Figure 9.7: Maximum Stress of the Carbon Fiber Material Rocket Motor Casing.

9.9.2 Strain

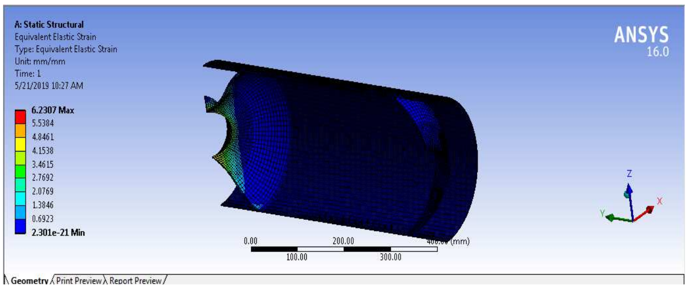


Figure 9.8: Maximum Strain of the Carbon Fiber Material Rocket Motor Casing.

9.9.3 Total Deformation

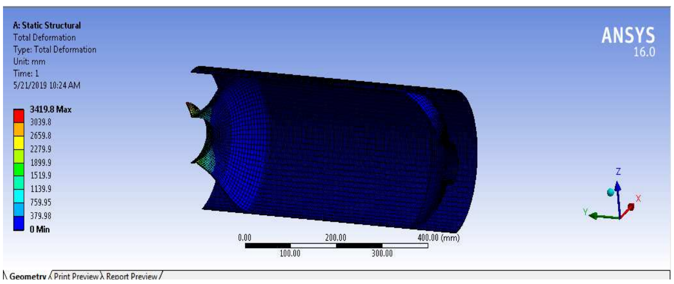


Figure 9.9: Total Deformation of the Carbon Fiber Material Rocket Motor Casing.

9.10 Material: Kevlar 29

9.10.1 Stress

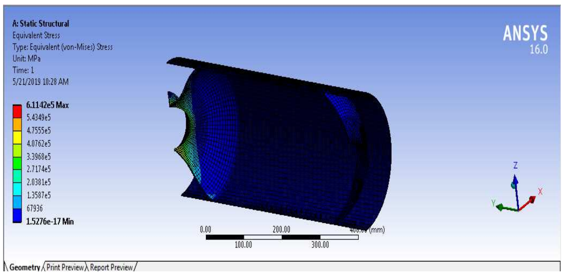


Figure 9.10: Maximum Stress of the kevlar 29 Material Rocket Motor Casing.

9.10.2 Strain

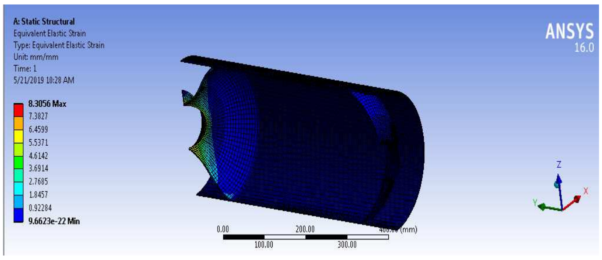


Figure 9.11: Maximum Strain of the Kevlar 29 Material Rocket Motor Casing.

9.10.3 Total Deformation

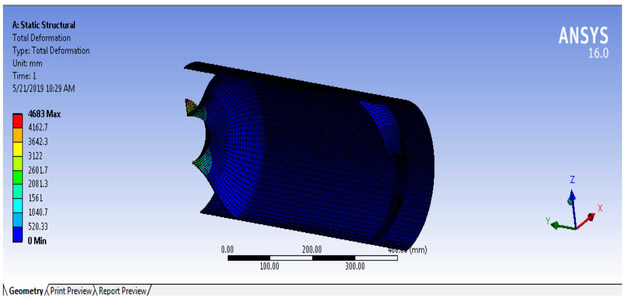


Figure 9.12: Total Deformation of the Kevlar.

29 Material Rocket Motor Casing

Material: Kevlar 49

Stress

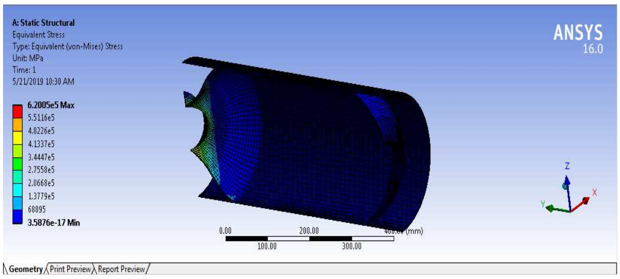


Figure 9.13: Maximum Stress of the kevlar 49 Material Rocket Motor Casing.

9.10.4 Strain

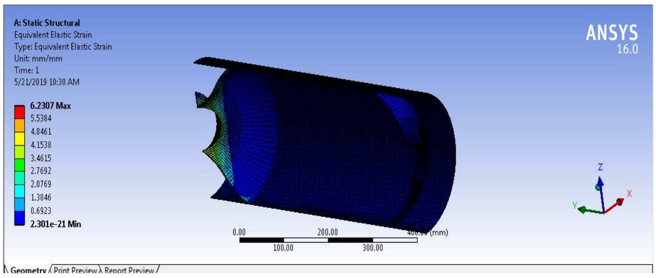


Figure 9.14: Maximum Strain of the Kevlar 49 Material Rocket Motor Casing.

9.10.5 Total Deformation

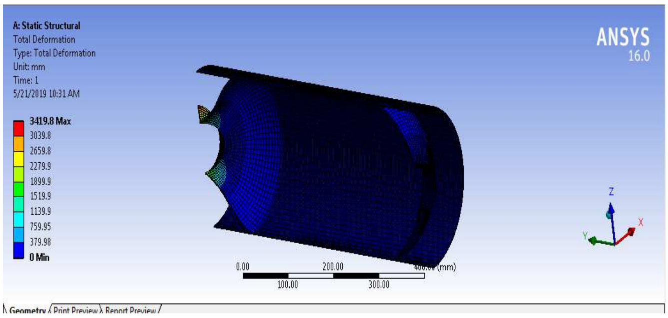


Figure: 9.15: Total Deformation of the Kevlar 49 Material Rocket Motor Casing.

9.11 Steady State Thermal Analysis

A steady-state thermal analysis can be used to determine temperatures, thermal gradients, heat flow rates, and heat fluxes in an item induced by non-varying thermal loads over time. The impacts of constant heat loads on a system or element are calculated by a steady state heat analysis. In order to help determine initial conditions, engineers often conduct a steady-state assessment before performing a transient thermal analysis. The last phase of a transient thermal analysis, conducted after all transient impacts have decreased, can also be a steady-state assessment. The ANSYS, Samcef, or ABAQUS solver can be used to perform a steady-state thermal analysis.

9.12 Applying Temperature

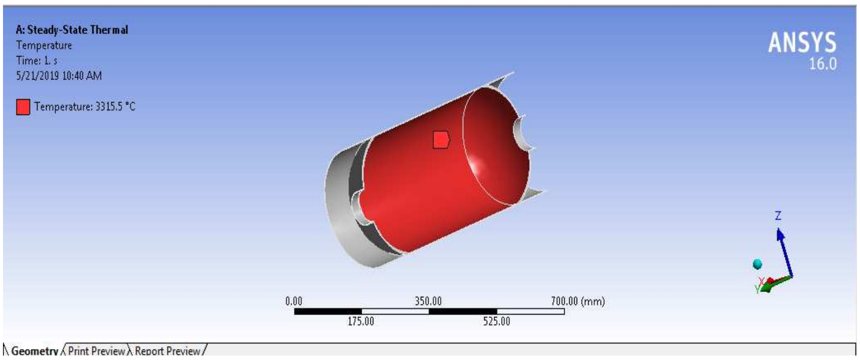


Figure 9.16: Temperature of 3315.5^{0}c Applied on Motor Casing.

9.13 Convection

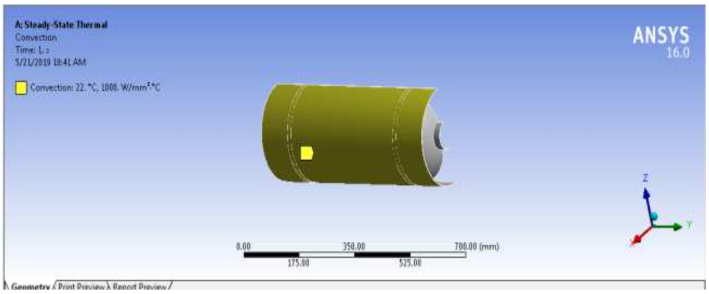


Figure 9.17: Convection of 1000 ^{0}c Applied on Motor Casing.

Material: Carbon fiber

Temperature Distribution

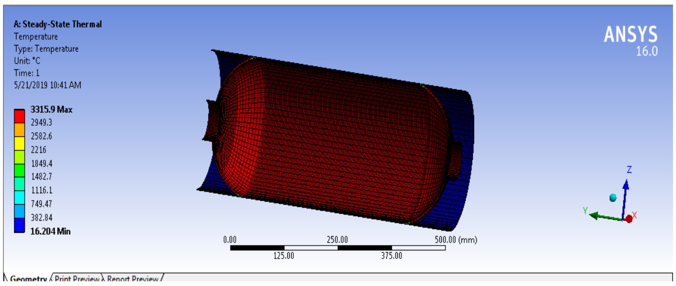


Figure 9.18: Temperature Distribution of the Carbon Fiber Material Rocket Motor Casing.

Total Heat flux

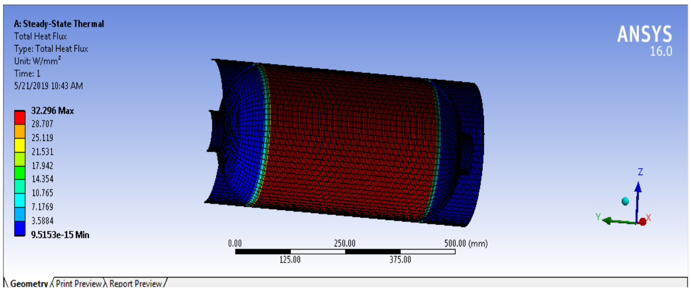


Figure 9.19: Total Heat Flux of the Carbon Fiber Material Rocket Motor Casing.

Material: Kevlar 29

Temperature Distribution

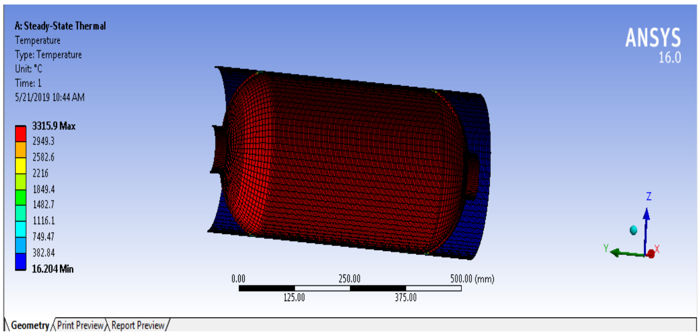


Figure 9.20: Temperature Distribution of the Kevlar 29 Material Rocket Motor Casing.

Total Heat flux

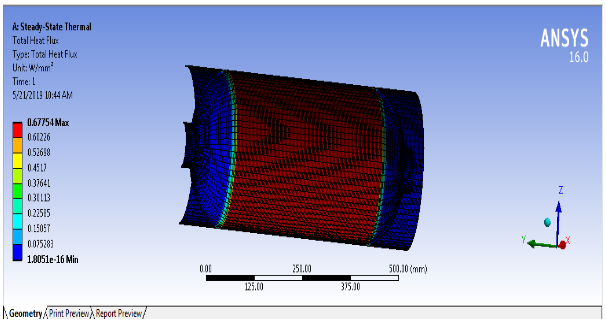


Figure 9.21: Total Heat Flux of the Kevlar 29 Material Rocket Motor Casing.

Material: Kevlar 49

Temperature Distribution

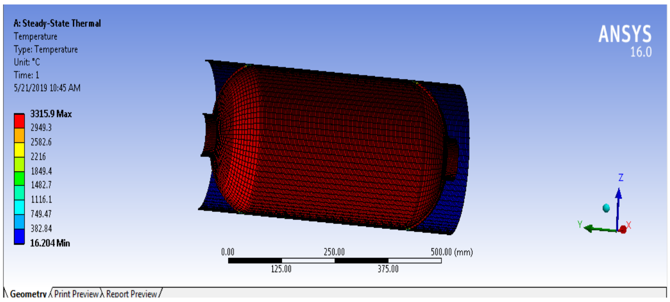


Figure 9.22: Temperature Distribution of the Kevlar 49 Material Rocket Motor Casing.

Total Heat flux

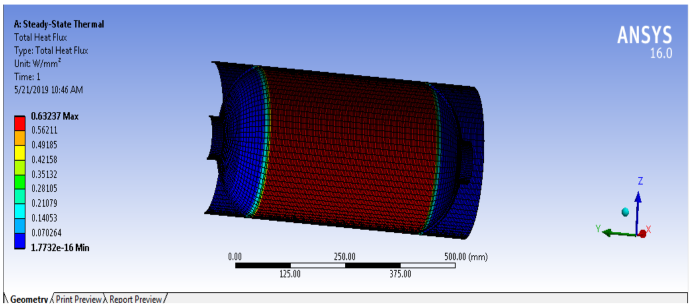


Figure 9.23: Total Heat Flux of the Kevlar 49 Material Rocket Motor Casing.

10. RESULTS

Modeling and analysis is performed on the casing of rocket motors. Modeling of rocket motor casing is carried out using different orders in solid works. Then the file will be saved to import into Ansys software as an IGES format. The casing of the solid rocket motor is imported into the workbench software Ansys 16.0. Structural analysis is carried out by applying stress, force and fixed support with three distinct composite materials such as carbon fiber, Kevlar 29 andKevlar-49 being changed. In the case of rocket motors, steel materials with high particular strength and excellent mechanical and thermal characteristics are used.

10.1 Static Structural Analysis

Table 2

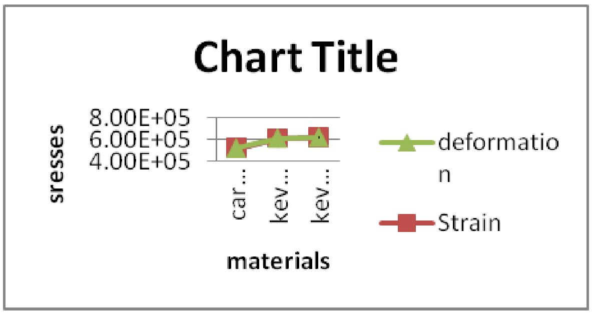
Material	Stress (Mpa)	Strain	Total deformation(mm)
Carbon Fiber	5.2005e[5]	5.2307	5419.8
Kevlar 29	6.1142e[5]	8.3056	4683
Kevlar 49	6.2005e[5]	6.2307	3419.8

10.2 Steady State Thermal Analysis

Table 3

Material	Temperature Distribution		Total heat flux
	Max	Min	(w/m²)
Carbon Fiber	3315.9	16.204	32.296
Kevlar 29	3315.9	16.204	0.67754
Kevlar 49	3315.9	16.204	0.63237

10.3 Graphs



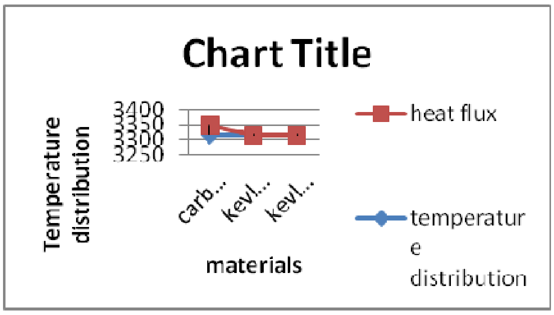


Figure 10: Static Structural Analysis and Steady State Thermal Analysis

11. CONCLUSIONS

Structural deformations such as stress, deformation and strain are found and tabulated. From the results rocket motor casing with Kevlar-29 material obtaining low stress and deformation values compared to other. Steady state thermal analysis is carried out on rocket motor casing by applying different materials such as, carbon fiber, Kevlar 29 and Kevlar-49 at temperature 3315.5°C. Temperature distribution and heat flux values are noted and are tabulated. From the analysis results are noticed that all the materials are showing equal temperature distribution. Thus, from the study it is conclude that Kevlar-29 material is more preferable compared to other materials.

Future Scope

- CFD Analysis for the Solid rocket engine packaging moreover to be performed.
- Composite Rocket engine packaging can be outlined what's more, contrasted and different materials.
- Design and analysis of solid rocket engine protection should be possible.

- CFD analysis for the solid motor casing moreover to be performed.
- Composite rocket motor casing can be outlined what's more, contrasted different materials.
- Design and analysis of rocket motor engine protection should be possible.

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